The Search for Dark Matter, and Xenon1TP

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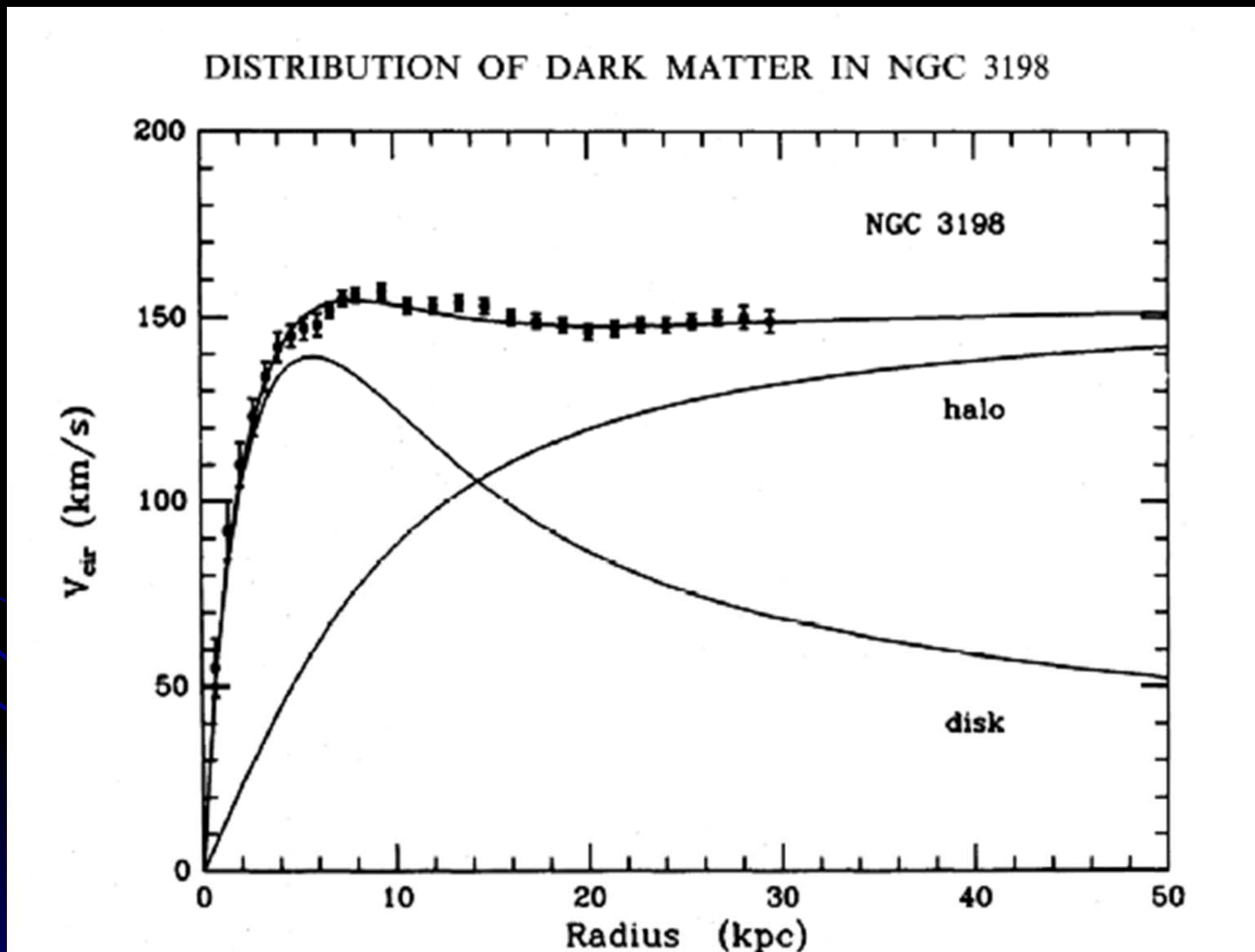
Galaxy NGC 3198

Galaxy NGC 3198 Rotation Curves



http://bustard.phys.nd.edu/Phys171/lectures/dm.html

Jamin Rager – Purdue Department of Physics

Coma Cluster Visible Range 0.5°

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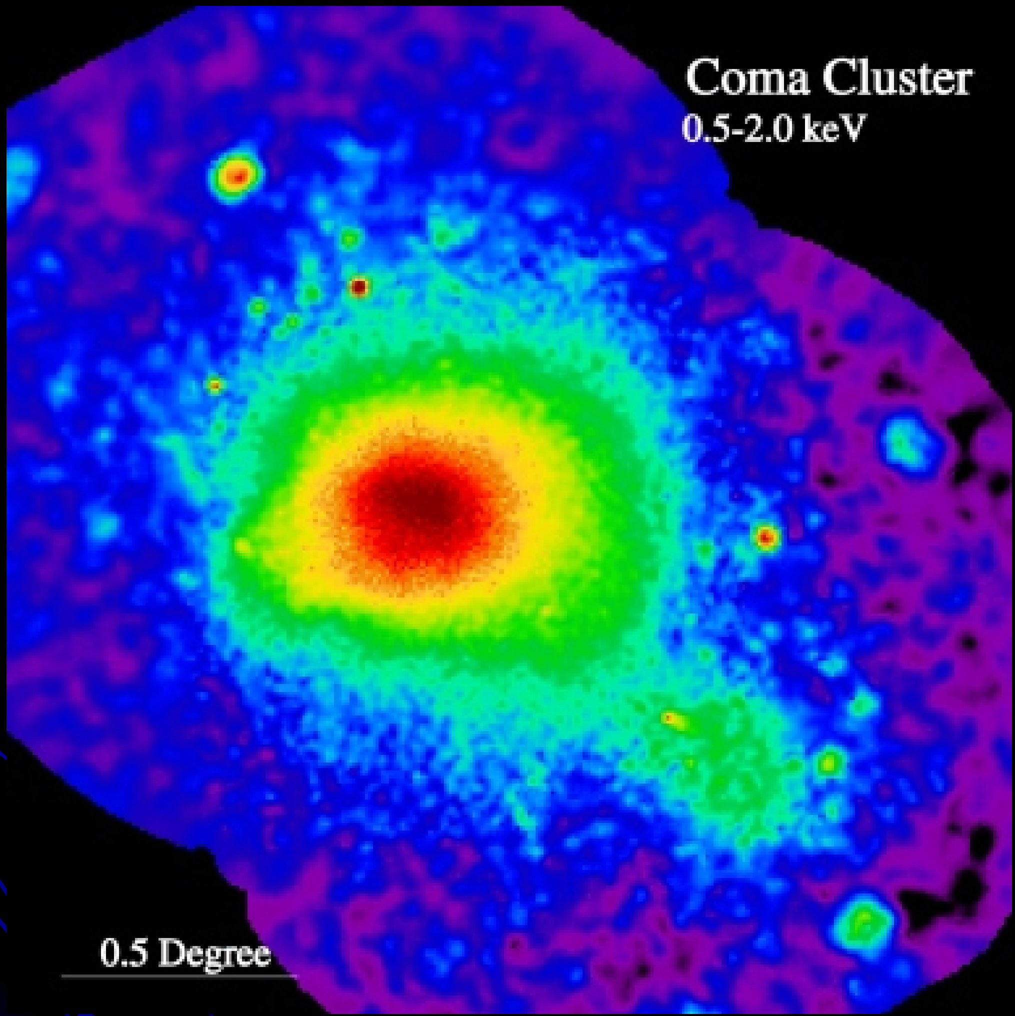
Coma Cluster X-Ray Range 0.5°



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Cluster 0024+1654 Lensing

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Baryonic Dark Matter

- Baryon → 3 quarks
  - protons & neutrons
- Massive Compact Halo Objects – MACHO
  - white dwarfs, brown dwarfs, neutron stars, planets, black holes
  - explains some gravitational lensing
- Flat universe geometry → universe at critical density ($\Omega_{tot} = 1$) → 90% matter non-baryonic → most DM non-baryonic

Hot Dark Matter

- Hot = high energy/velocity (highly relativistic)
- Large mean free path
- Already observed - neutrinos
  - only gravitational & weak interactions
  - produced soon after Big Bang (before decoupling of light)

Problems with HDM

- Small fluctuations in ρ_{mass} smoothed out
  - top-down formation? No, backwards!
  - cosmic defects (cosmic strings)? No, can't explain temp. fluctuations in CMB
  - not enough of it
- So, what then?

Cold Dark Matter

- Cold = slow, less energetic, smaller mean free path
  - small ρ_{mass} fluctuations possible (bottom up structure formation)
- Predicts temperature fluctuations in CMB
- WIMP's – new, undiscovered particles
  - massive (slow)
  - "invisible" (no EM or strong interactions)

WIMP Candidates

- Super-symmetric particles
  - neutralino – 10-10000 GeV, produced thermally early univ., right abundance
- Super-symmetry
  - partners have same quantum numbers (sans spin, differ by ½)
  - universe cools, super-symmetry breaks, least massive super-symmetric particle(s) survive

Detection of WIMP’s

- Indirect methods

  - synthesize them in colliders (LHC), look for apparent violation of conservation

  - special telescopes (search for products of WIMP annihilations)
- Direct

  - cryogenic

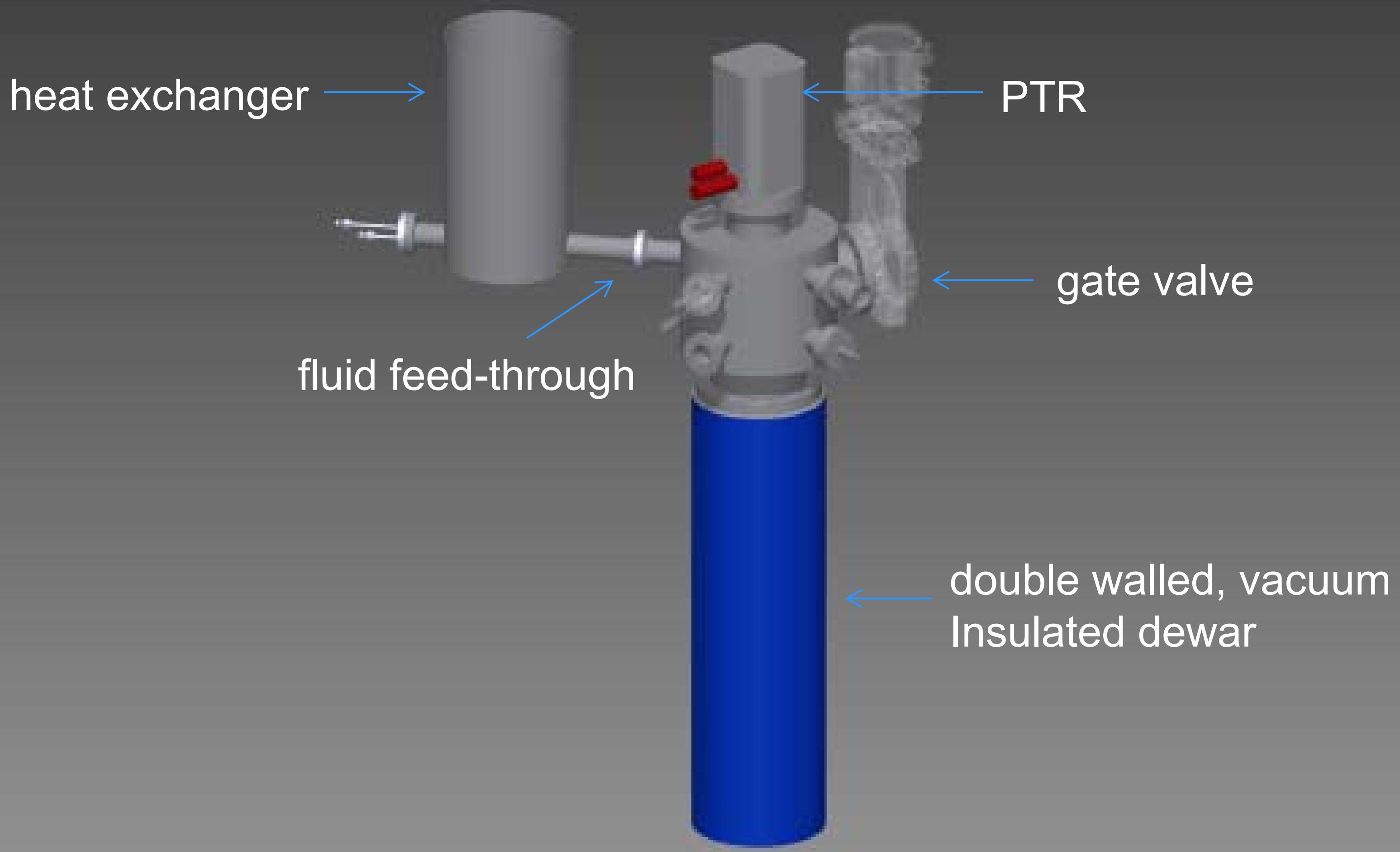
  - scintillation

Our Work

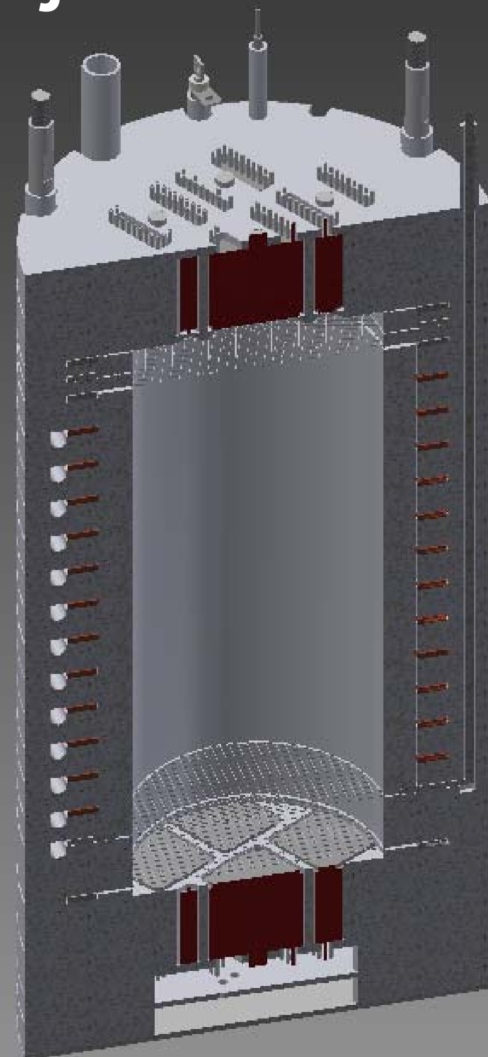
- The search
  - direct detection – our method
  - XENON10, XENON100, XENON1T – liquid scintillators

  - calibration and prototype

XENON1TP


heat exchanger
PTR
gate valve
fluid feed-through
double walled, vacuum
Insulated dewar

Time Projection Chamber



Universität Münster

Steady State Heat Transfer

- Conduction:

$$\vec{q} = -k\vec{\nabla}T \quad \Leftrightarrow \quad \overrightarrow{\nabla^2}T + \frac{\dot{e}}{k} = 0$$

Convection:

$$\dot{Q} = -hA(T_s - T_A), \quad if\ h \approx const.$$

Radiation:

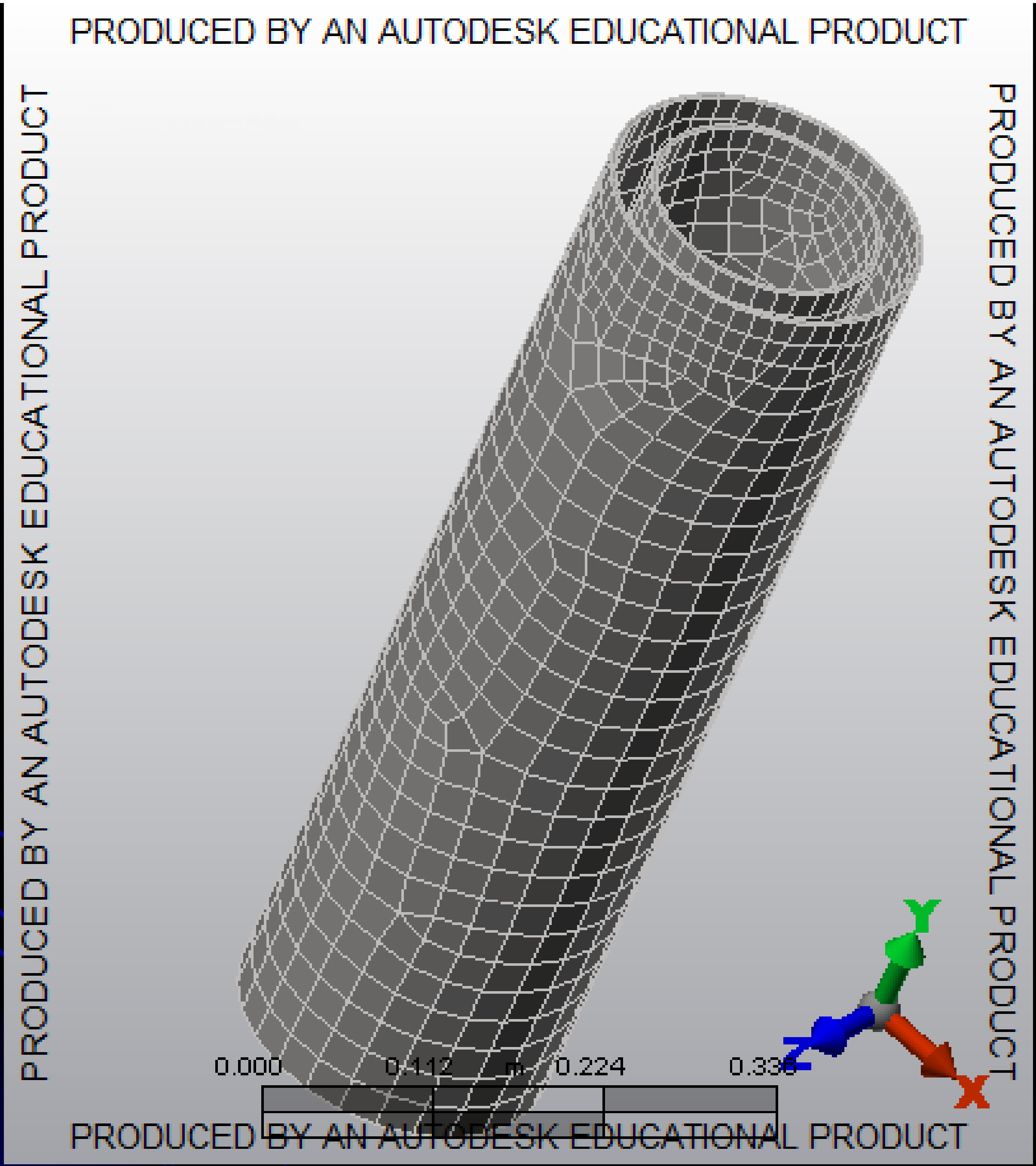
$$\dot{Q}_{1\to2} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\epsilon_1}{A_1\epsilon_1} + \frac{1}{A_1F_{1\to2}} + \frac{1-\epsilon_2}{A_2\epsilon_2}}$$

Finite Element Analysis

- FEA – Numerical solutions to PDE's
  - Discretize domain – mesh of nodes
  - Replace PDE with discrete algebraic system

$$\iint_D W_i R = 0, \quad i = 1,2,\ldots,n$$

- Find heat loss of Xe1TP – how much cooling power necessary?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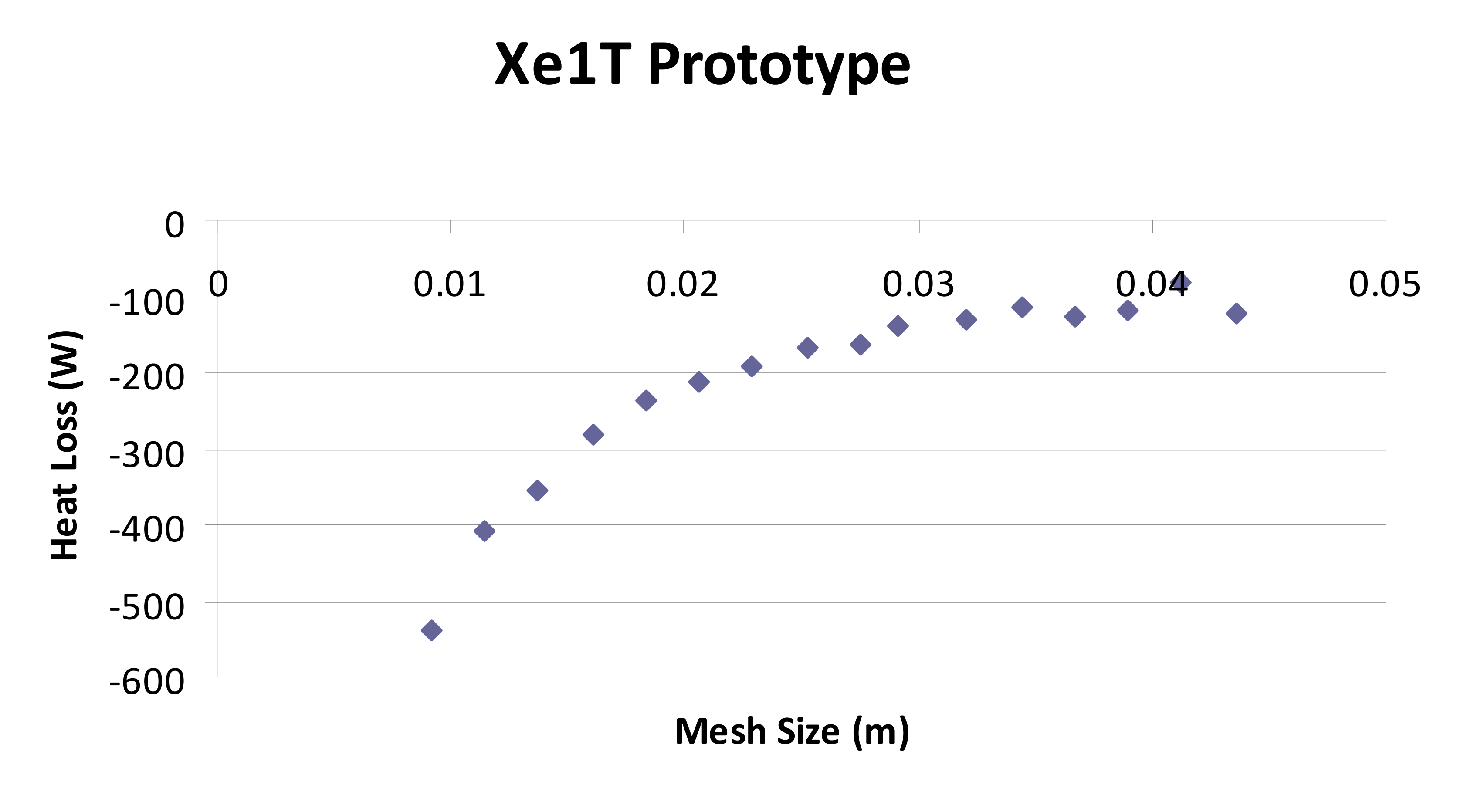
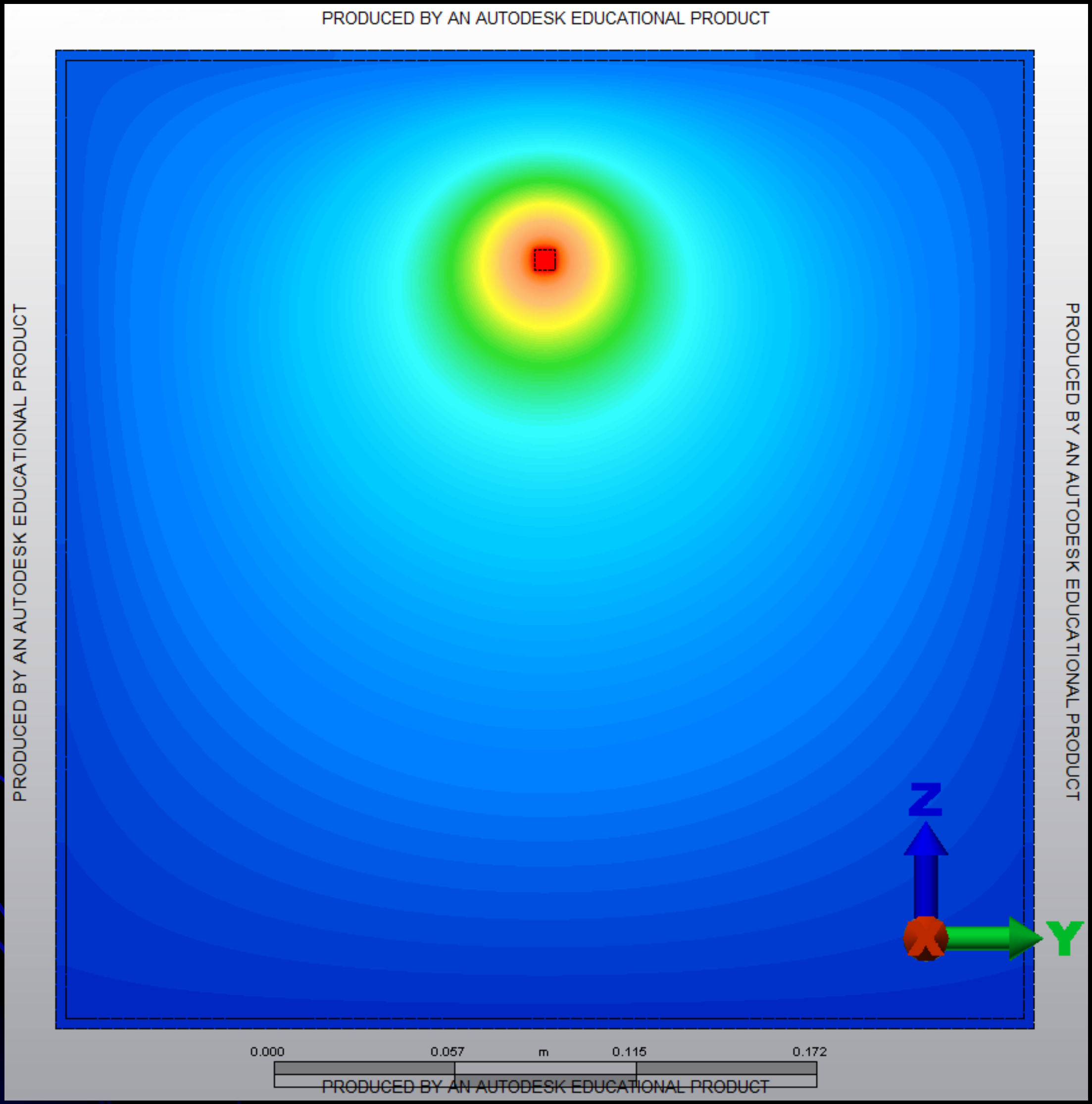
Mesh Convergence Study



2D Metal Box



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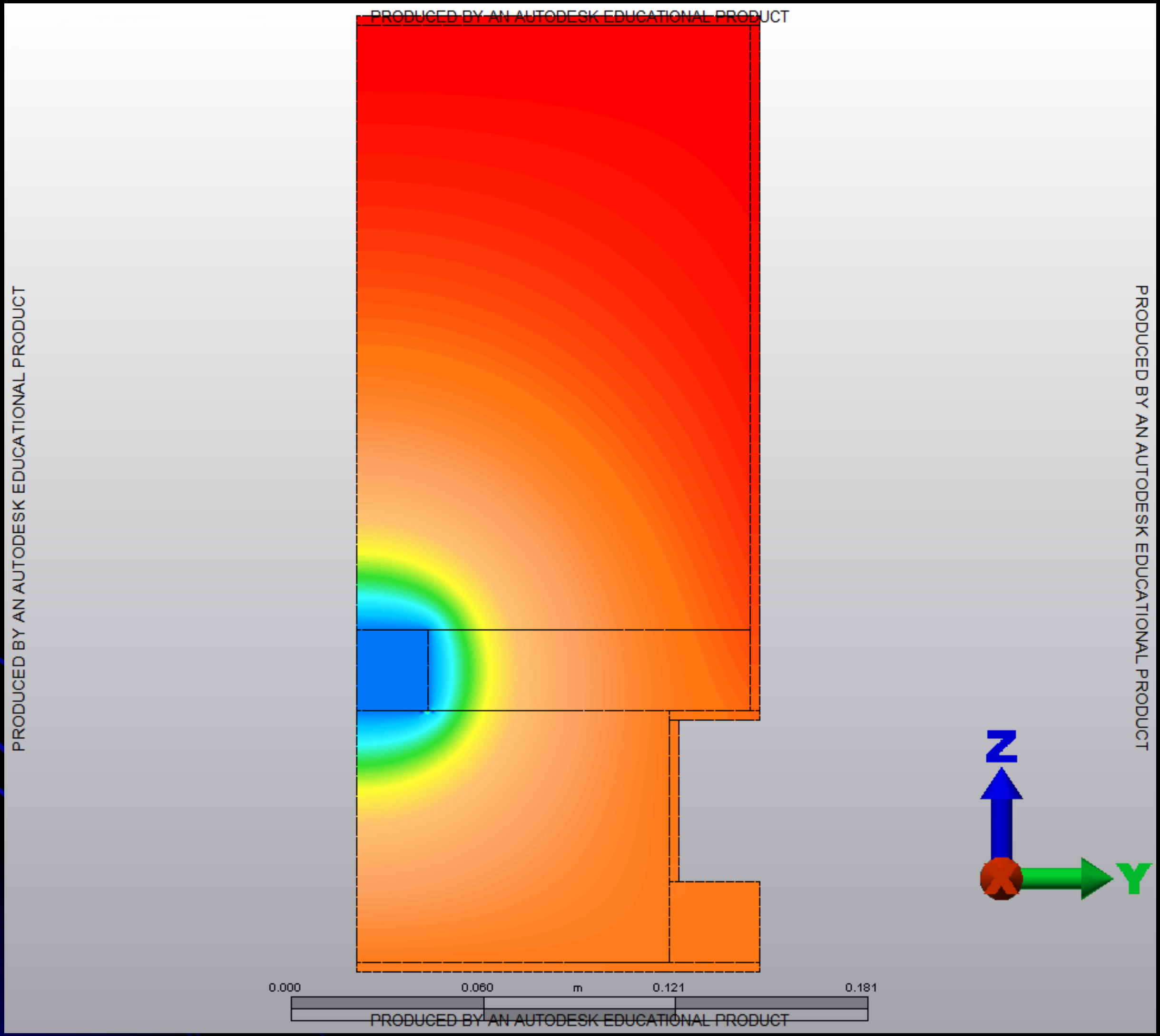
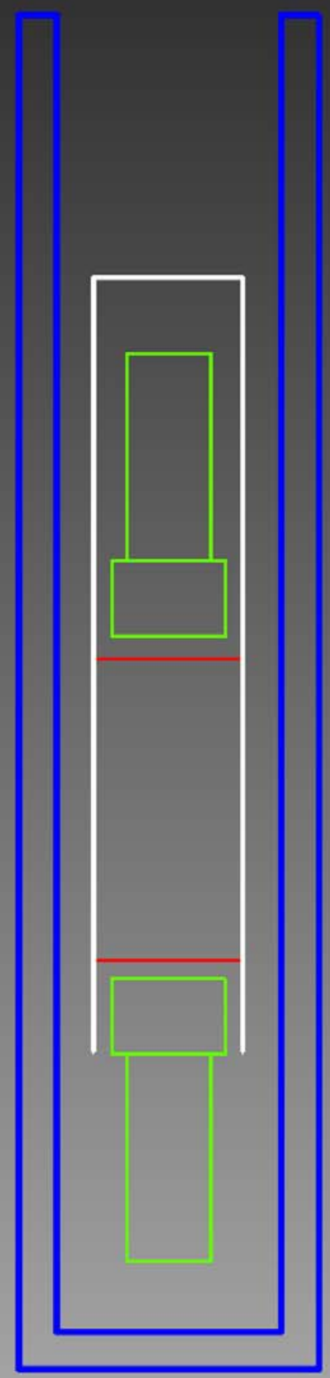
Xe1TP Top Mount



Results

	Species	Heating Means	Heat Flow (W)
Metal Box	Xenon gas	c.f. (1.78” x 1”)	17.6
XENON1TP	Xenon gas	c.f. (1.78” x 1”)	9.8

Finis



Direct Detection

- Cryogenic (<100mK)

  - detect heat from collision w. atom in crystal absorber
- Scintillation

  - crystal

    - ~DAMA/NaI – purported success

  - noble liquid

    - ~XENON

XENON 100

- Goal - spin-independent WIMP-nucleon scattering σ sensitivity of 2×10^{-45} cm^2 for 100 GeV/c^2 WIMP.

  \- low intrinsic radioactivity materials

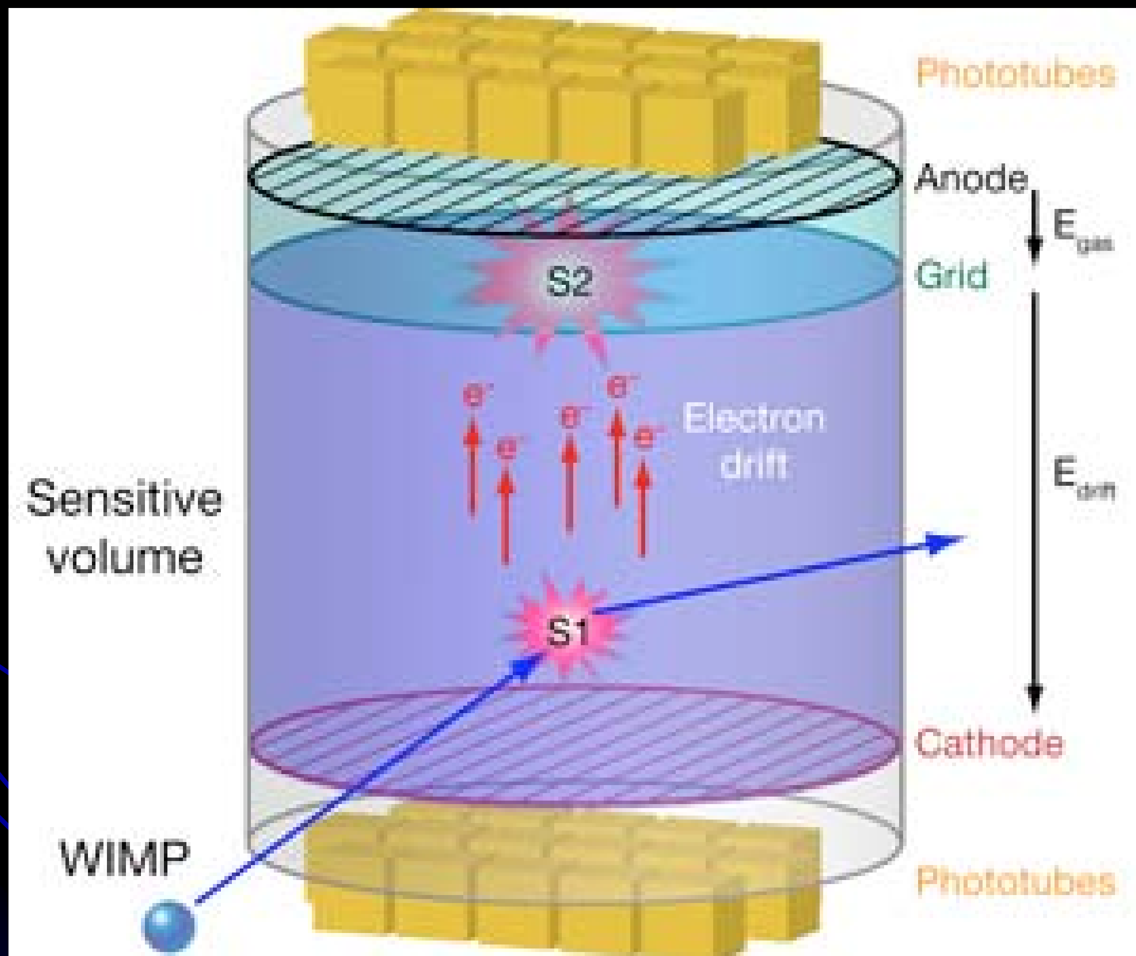
  \- passive and active shielding

  - ~passive: 5 cm copper, 20 cm PE, 20 cm lead, 20 cm water or PE, entire shield rests on 25 cm thick slab PE, underground (equivalent 3700m water)

XENON 100

- Active shield: 4cm LXe monitored by PMT
  - LXe high stopping power
- 2 phase (liquid,gas) scintillation in TPC
  - direct: LXe WIMP-atom interaction, S1
  - secondary: gas Xe, ionization e- from phase 1 → proportional scintillation, S2
- S2/S2 a data filter

XENON 100 Artist Rendering



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XENON 100 – Top Array

http://bustard.phys.nd.edu/Phys171/lectures/dm.html

XENON 100

- TPC – h = 30.5cm r = 15.3cm, 62kg target
  - 3D vertex reconstruction
    - ~ Δt signals → drift time of e- → z coordinate, 2mm accuracy
    - ~ x & y from Monte Carlo simulation, 3mm accuracy

Sources

1. http://astro.berkeley.edu/~mwhite/darkmatter/hdm.html
2. http://bustard.phys.nd.edu/Phys171/lectures/dm.html
3. http://curious.astro.cornell.edu/question.php?number=689
4. http://meetings.aps.org/Meeting/APR11/Event/145975
5. http://www.astro.caltech.edu/~george/ay21/eaa/eaa-hdm.pdf
6. http://www.pbs.org/wnet/hawking/strange/html/strange_hotcold.html
7. http://physics.aps.org/articles/v3/78
8. http://www.physik.uzh.ch/groups/groupbaudis/xenon/
9. http://www.sciencedirect.com/science/article/pii/S0927650512000059#gr1
10. http://wwwme.nchu.edu.tw/Enter/html/lab/lab516/Heat%20Transfer/chapter_2.pdf